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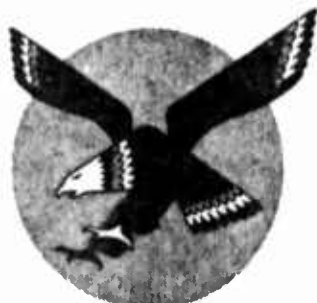
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HEAT TRANSFER RATES TO 1/50TH SCALE MODELS
OF THE ATLAS FOREBODY WITH G.E. MARK II AND CONVI
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AVCO SERIES 4 REENTRY BODY CONFIGURATIONS

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SUMMARY:

Heat transfer measurements were made in a high temperature wind tunnel on 1/50th scale models of the Atlas forebody with the General Electric Mark II and Avco Series 4 Re-entry Bodies. The tests were made to provide data to be utilized in heat transfer calculations on the Atlas missile forebody.

The models were exposed to a Mach 6.3 flow of hydrogen-air combustion products with a total temperature of 4350°R. Heat transfer measurements were taken in the vicinity of surface discontinuities along the missile profile. Heat transfer rates were highest upstream of the first discontinuity and dropped to approximately 30% of their initial values on the downstream sections of both models. Pressure measurements were taken forward and aft of stations 502 and 645.

TEST APPARATUS AND PROCEDURE:

The models were tested in the Thermodynamics Laboratories high temperature wind tunnel. Gaseous hydrogen and air were burned at stoichiometric mixture ratio at a pressure of 465 psia. The combustion products were expanded through an axisymmetric reflex nozzle into a 6.75 inch diameter test section. The exhaust gases were removed by a 450-pound thrust rocket ejector and four Roots blowers powered by Allison aircraft engines. A diagram of the tunnel is given in Figure 1.

Combustion chamber properties were calculated for stoichiometric combustion of hydrogen and air at 465 psia. The free stream properties in the test section were determined by expanding the gases at frozen composition through small pressure increments from the combustion chamber to the measured test section pressure of 0.105 psia. The combustion chamber and test section properties are listed in Tables 1 and 2.

As part of the investigation of the test section properties, heat transfer measurements were taken on a flat plate to determine the condition of the boundary layer. When compared to theoretical heat transfer rates for laminar and turbulent boundary layers, the experimental data show closer agreement with the laminar values. This comparison is presented in Figure 2.

The models used in this study, were constructed to 1/50th scale of missile dimensions. They were fabricated from stainless steel sections held together by a bolt through the longitudinal axis of the models (Figures 3 - 6). The skin in the vicinity of the surface discontinuities was machined to a 0.050 inch thickness, and chromel-alumel thermocouples were tack-welded to the inside surface. The models were instrumented approximately 1/2 inch forward and aft of the discontinuities, and pressure taps were installed 0.25 inches forward and aft of Stations 502 and 645 (Figures 7 and 8).

The areas of primary interest in this investigation were in the vicinity of surface discontinuities. Instrumentation was limited to these regions to simplify

TEST APPARATUS AND PROCEDURE: (Cont'd)

model construction. Because of physical limitations in model construction, and prior availability of stagnation heat transfer data, a thermocouple was not installed at the stagnation point. The stagnation point heat transfer rate previously measured on a 1.25 inch diameter blunt body under identical tunnel conditions was 68.5 BTU/ft² sec.

The models were exposed to the tunnel flow for approximately 3 seconds. Temperature histories sensed by the thermocouples were recorded with a light-beam oscillograph. Pressure variations were measured by variable inductance-type transducers and also recorded by a light-beam oscillograph.

DATA REDUCTION:

Heat transfer rates were calculated from the recorded temperature-rise rates and properties of the model material. A heat balance taken on an element of the model wall shows that the total heat flow into the element, less the heat added or lost through lateral conduction and radiation at the inside surface, is equal to the heat stored in the element.

$$Q_{in} = Q_{stored} + Q_{conduction} + Q_{radiation}$$

Conduction and radiation losses were determined by measuring the heating or cooling rates on the model after the flow had been stopped. The rate of temperature increase measured during the flow was then corrected to give a rate of temperature increase which would be experienced if the losses did not exist. Radiation effects were calculated analytically and were found to be equal to approximately 2% of the heat taken into the wall at the maximum measured temperature.

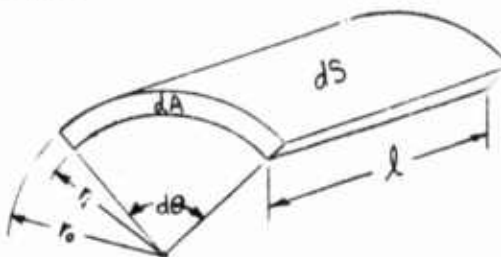
The corrected temperature-rise rate was then used in the heat balance to calculate the heat transfer rate. The following equation was used.

$$qds = \rho C_p dV \left(\frac{dT}{dT} \right)_{corr.}$$

Where: q = Heat flux into the element, BTU/ft² sec,
 s = Outside surface area of the element, ft²
 ρ = Specific weight of element material, lb/ft³
 C_p = Specific heat at constant pressure, BTU/lb. °F
 V = Volume of element, ft³
 $\left(\frac{dT}{dT} \right)_{corr.}$ = Corrected temperature-rise rate, °F/sec.

DATA REDUCTION: (Cont'd)

Approximating the model wall with a hollow cylinder, the volume and surface area can be expressed as follows:



$$S = 2\pi r_o l$$

$$V = \pi(r_o^2 - r_i^2) l$$

Substituting these equations into the heat balance, the following equation is obtained.

$$q = P C_p \frac{(r_o^2 - r_i^2)}{2r_o} \left(\frac{dT}{dr} \right)_{\text{CORR}}$$

The results of these calculations are presented in Table 3 and in Figure 9 and 10.

DISCUSSION:

The highest heat transfer rate was measured forward of the first surface discontinuity on the model with the G.E. configuration. This value of 31.0 BTU/ft² sec is 16% higher than those measured on the forward portion of the AVCO nose cone. In general, the models experienced the highest heat transfer rates forward of the first surface discontinuity. The rates dropped rapidly as the flow expanded over the discontinuity, remaining fairly uniform at approximately 30% of their initial values on the downstream sections of the models.

As the flow approached a compression corner a slight decrease in heat transfer was noted. The heat transfer rates then increased as the flow was turned at the corner. The opposite effect was noted as the flow approached an expansion corner. The heat transfer rates on the AVCO configuration were 30% higher in the vicinity of Station 645 than on the G.E. configuration, although distribution of the rates in this region is similar. This may be due to boundary layer disturbances caused by reflection of local shock waves from the shock envelope.

The pressure measurements (Table 4) show a pressure rise as the flow expanded over Station 645 on the AVCO Model. This rise, when compared to the drop measured on the G.E. Model, seems to indicate the presence of a boundary layer disturbance. Because of a malfunction in the transducer circuit, pressure data of tap number one was not obtained for the AVCO Model.



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TABLE I

COMBUSTION CHAMBER GAS COMPOSITION
AND PROPERTIES FOR STOICHIOMETRIC COMBUSTION OF H_2 - AIR

MOLECULAR SPECIES	MOLE PERCENT
H_2O	33.65
N_2	64.84
H_2	0.721
O_2	0.218
OH	0.298
NO	0.216
H	0.033
O	0.0225
N	0.0000

CHAMBER PRESSURE, PSIA	465
COMBUSTION TEMPERATURE, °R	4350
TOTAL ENTHALPY, BTU/lb.	1551
MOLECULAR WEIGHT	24.43

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TABLE 2

TEST SECTION FLOW PROPERTIES

	CALCULATED	MEASURED
MACH NUMBER	6.3	6.5
VELOCITY, FT/SEC	8,450	
REYNOLDS NUMBER	3.35×10^5	
SPECIFIC HEAT RATIO	1.37	1.33
TOTAL TEMPERATURE °R	4350	
STATIC TEMPERATURE °R	640	
STATIC PRESSURE, PSIA	0.105	0.105

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TABLE 3HEAT TRANSFER RATES FOR 1/50TH SCALE MODEL OF ATLAS
FOREBODY WITH GENERAL ELECTRIC MARK II RE-ENTRY VEHICLE

T.C. NO.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F	T.C.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F	T.C.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F
1	6.28	164	10	9.50	170	19	6.35	217
2	5.31	160	11	8.50	164	20	6.93	216
3	5.31	158	12	7.22	222	21	7.28	223
4	6.28	159	13	7.22	231	22	6.53	268
5	5.80	159	14	7.12	212	23	8.59	289
6	6.76	161	15	7.46	217	24	12.3	330
7	7.25	165	16	6.76	218	25	17.7	435
8	10.0	173	17	6.76	218	26	31.0	664
9	10.5	172	18	5.76	212			

HEAT TRANSFER RATES FOR 1/50TH SCALE MODEL OF ATLAS
FOREBODY WITH AVCO SERIES 4 RE-ENTRY VEHICLE

T.C. NO.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F	T.C.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F	T.C.	$\frac{q}{\text{sec}}$ BTU/ft ²	T °F
1	---	---	13	8.85	263	25	5.94	205
2	5.31	138	14	8.85	272	26	5.50	197
3	6.28	146	15	9.09	274	27	3.77	164
4	7.25	153	16	9.09	270	28	4.44	167
5	7.73	156	17	9.32	273	29	4.00	164
6	8.69	166	18	10.5	290	30	4.22	162
7	10.1	176	19	10.0	288	31	8.44	243
8	13.0	196	20	10.3	281	32	11.3	284
9	13.5	201	21	10.3	284	33	12.4	316
10	13.5	203	22	6.60	233	34	16.4	400
11	13.0	199	23	6.60	235	35	20.9	472
12	8.16	257	24	5.72	202	36	26.8	516

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REPORT NO. RT 60-106.1TABLE 4PRESSURE DISTRIBUTION ALONG THE SURFACE
OF 1/50TH SCALE MODEL OF ATLAS FOREBODY

PRESSURE TAP	G.E. MARK II		AVCO SERIES 4	
	P Inches HgA	$\frac{P}{P_{\infty}}$	P Inches HgA	$\frac{P}{P_{\infty}}$
1	0.62	2.95	---	----
2	0.81	3.86	0.80	3.81
3	1.12	5.33	0.70	3.33
4	0.96	4.57	1.88	8.95
5	1.08	5.14	0.75	3.57

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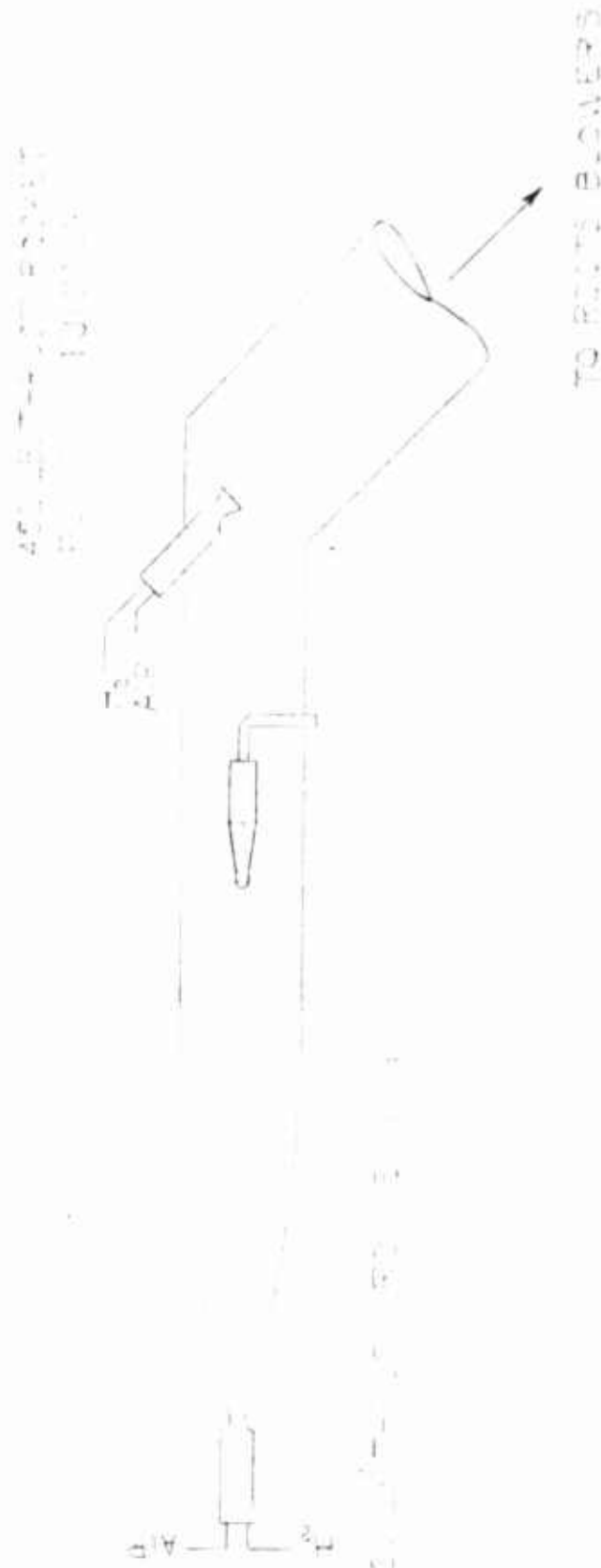
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Fig. 1 High temperature wind tunnel

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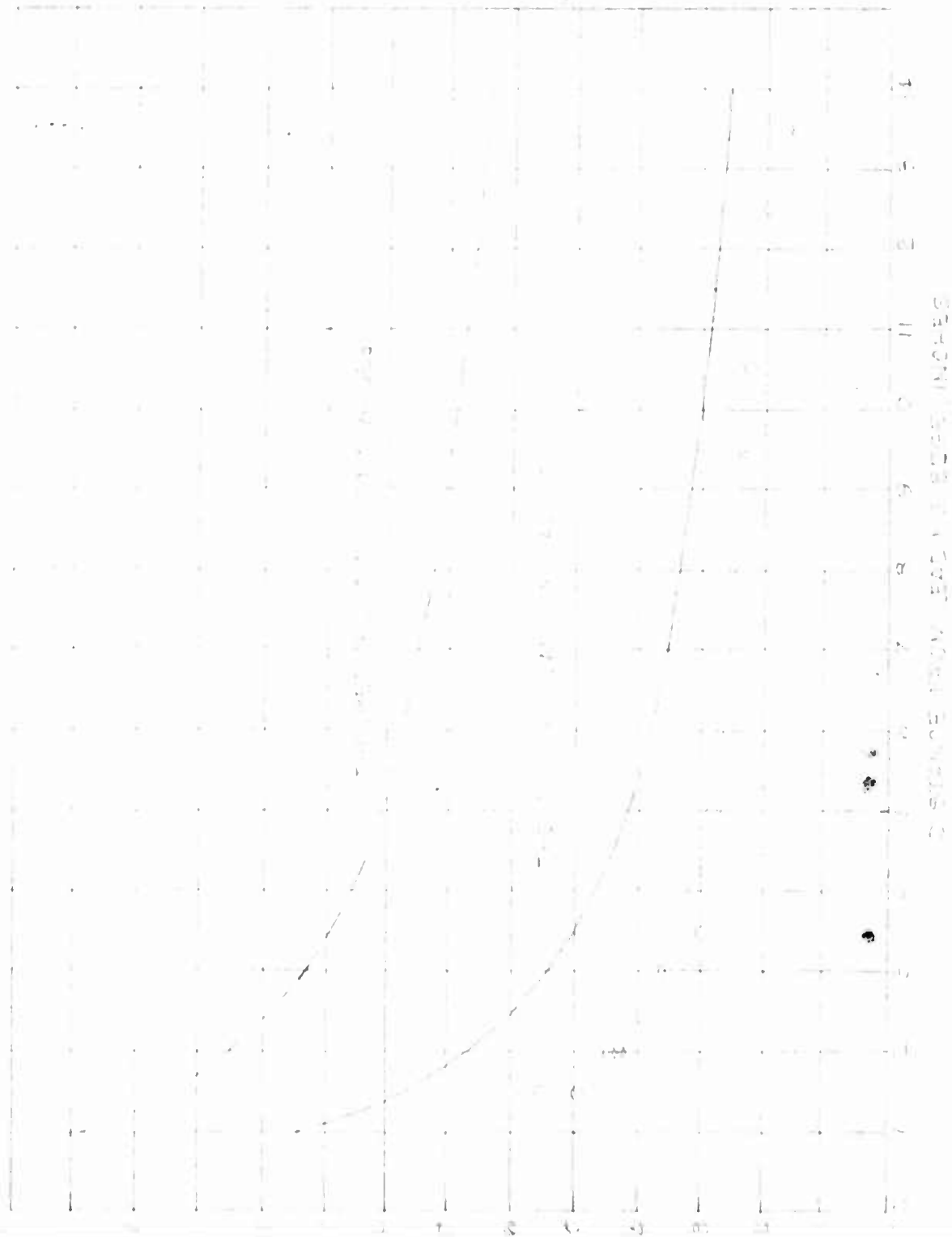


Fig. 2 Heat transfer data for flow over a flat plate

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Fig. 3 Construction of Atlas model with G.E. Mark II nose configuration



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Fig. 4 Construction of Atlas model with AVCO Series 4 nose configuration



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GE Mark II Re-entry Body on Forward Section of Model After Exposure to Tunnel Flow

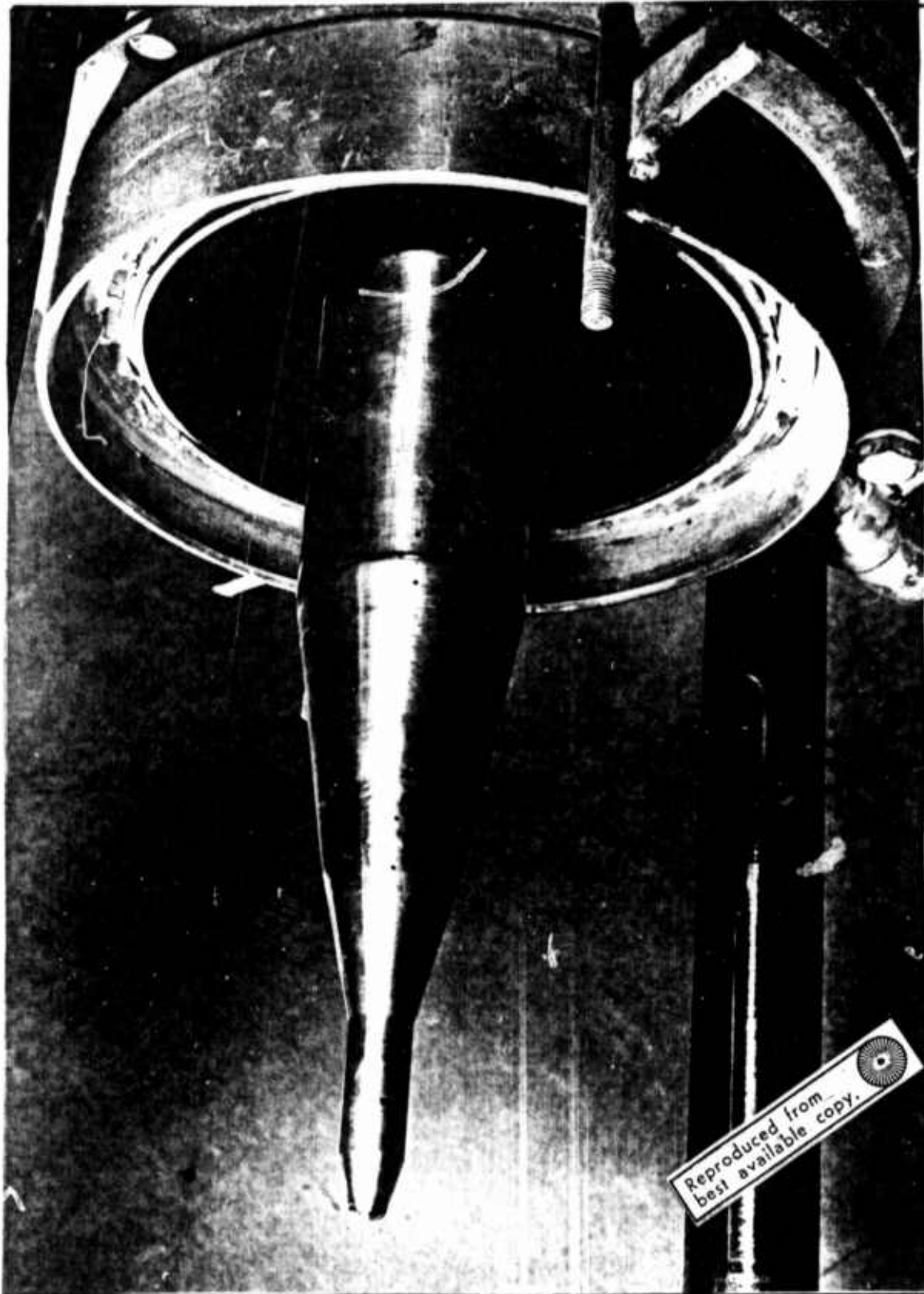
Figure 5



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Photograph of AVCO Series 4 Reentry Body on Atlas Forebody

Figure 6

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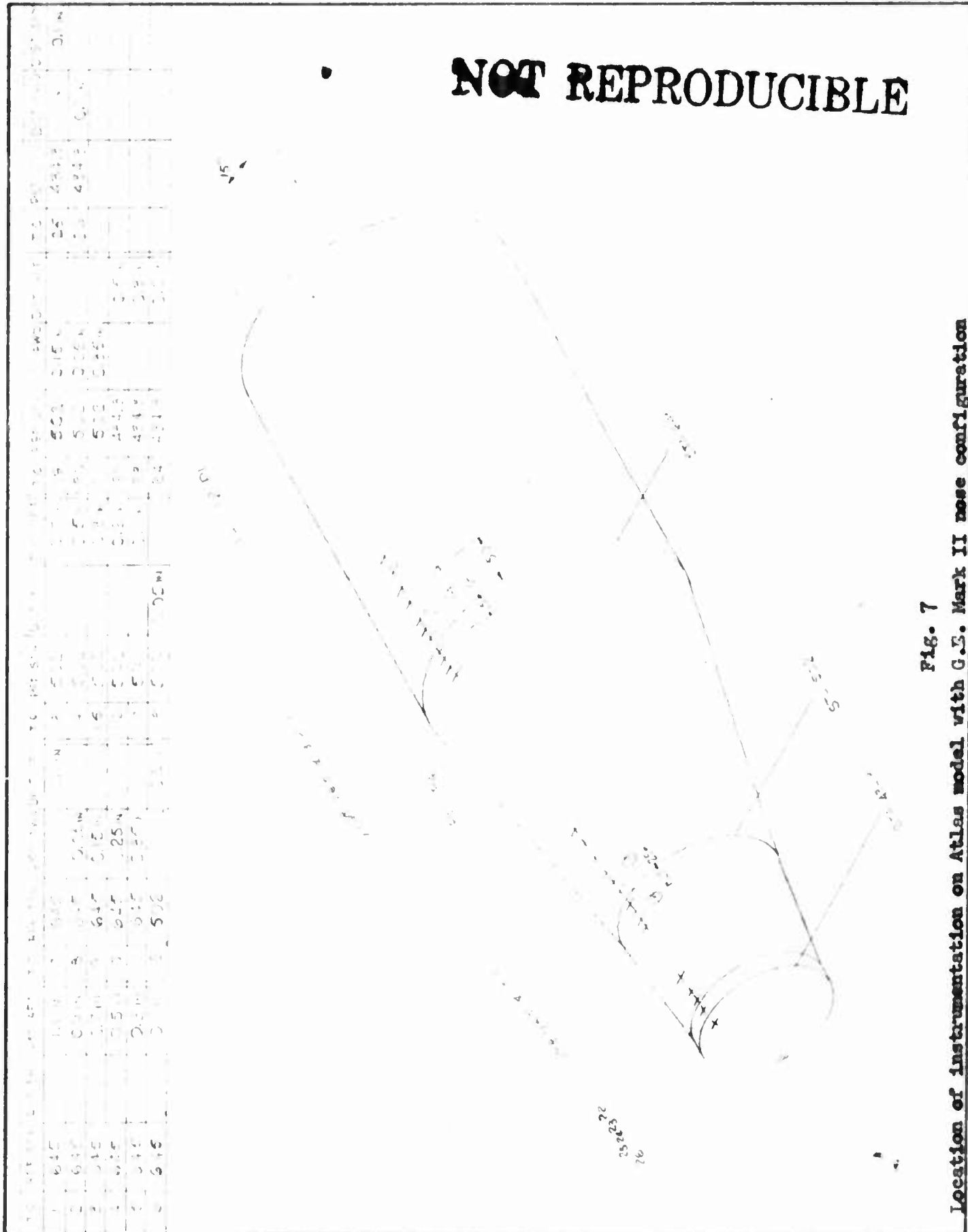
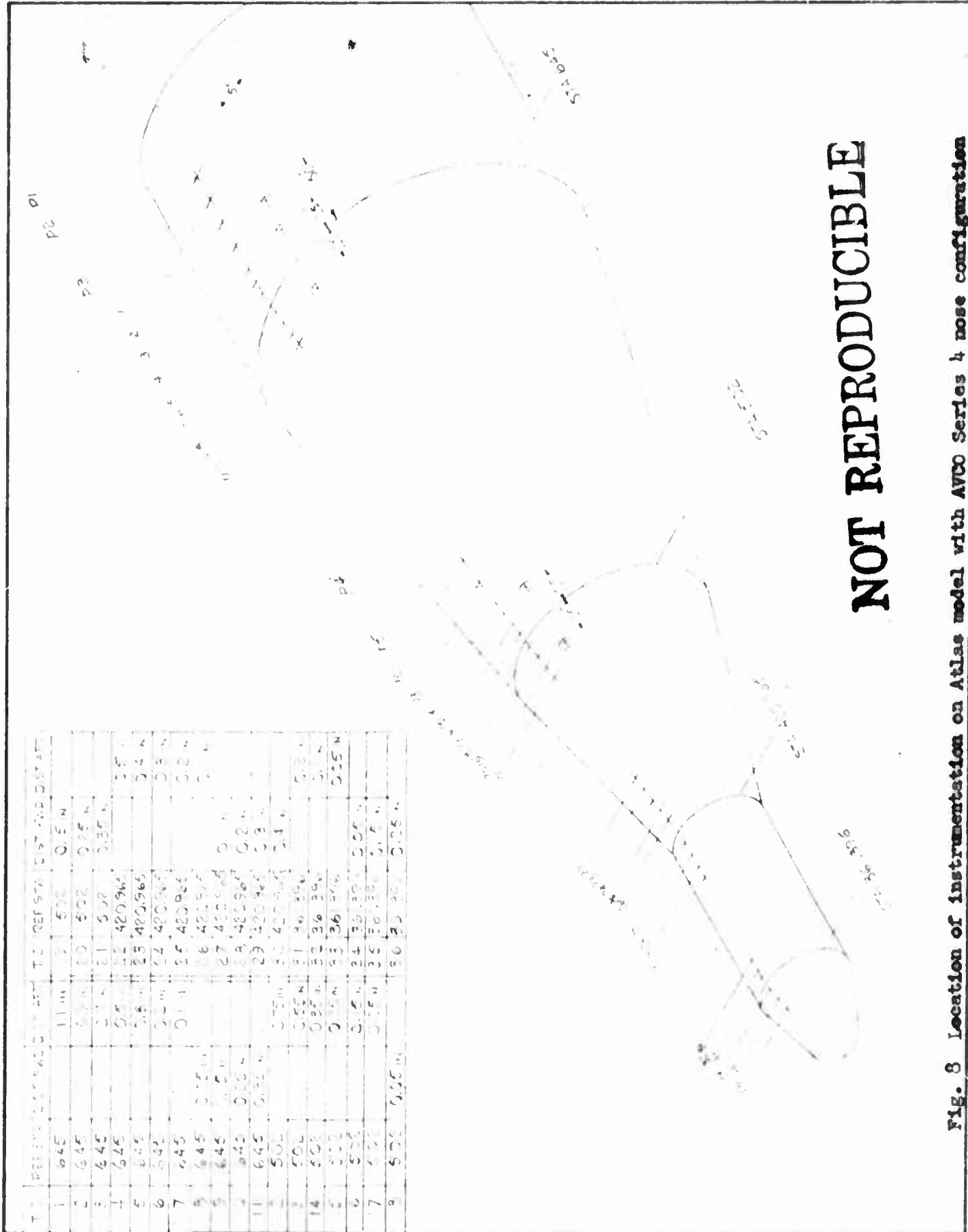


Fig. 7

Location of instrumentation on Atlas model with G.S. Mark II nose configuration



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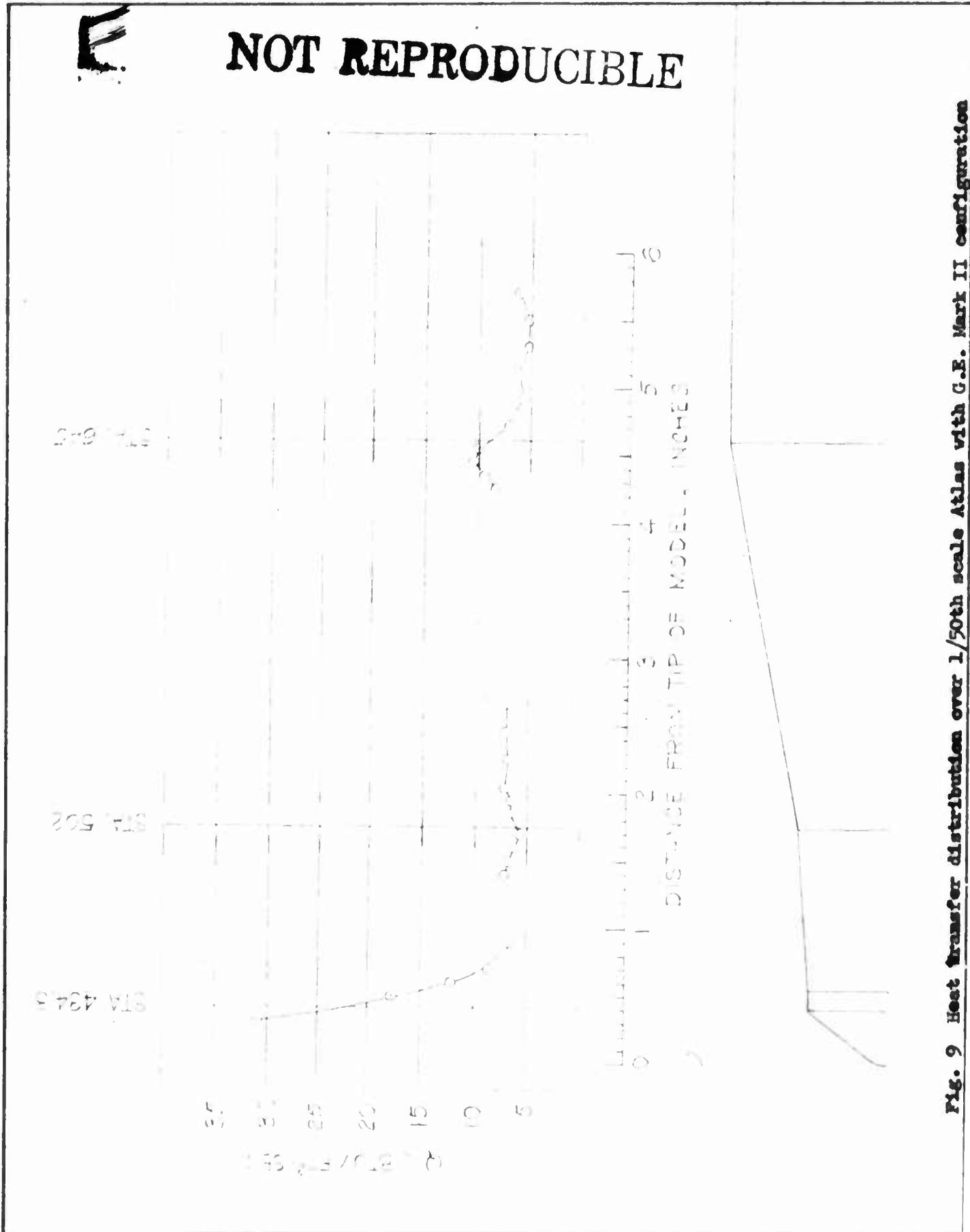


Fig. 9 Heat Transfer Distribution over 1/50th scale Atlas with G.E. Mark II configuration



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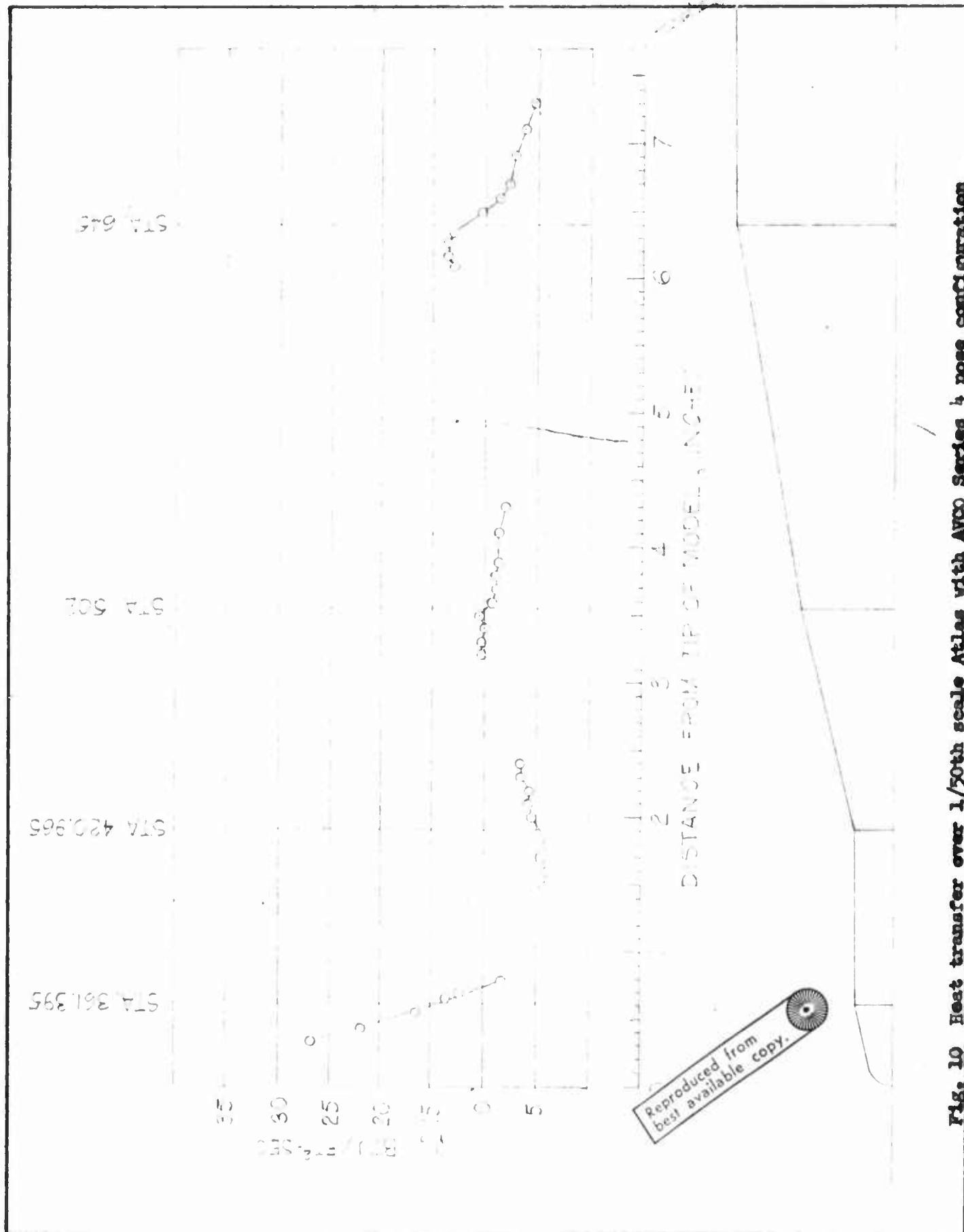


Fig. 10 Heat transfer over 1/50th scale Atlas with AVCO Series 4 nose configuration

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